Self Healing Concrete: A Review

Devesh Thaker

Mukesh Patel School Of Tech Management & Engineering, Mumbai, India

Key words: Self-Healing Concrete, Microbial Healing concrete, Cost saving, Environment friendly.

ABSTRACT

It is now one of the green and environmentally friendly method of repairing concrete cracks with microbial induced calcium carbonate precipitation (MICP). However, these studies are practiced at laboratory level, and functional engineering applications are rarely conducted. Therefore, to promote the use of microbial cement mortar, a study of microbial healing agents and self-healing concrete was performed. Subsequently, microbial-reinforced concrete construction technologies were tested in the practice of engineering. The results showed that the spray-dried bacterial spray system has a high potential for powder-based and capsule based microbial production. Compared with liquid-based healing agents, they were much easier to produce, transport, store and use. To ensure self-healing effects, the necessary cooling measures should be taken to keep the cracks moist and to provide nutrients. Self-efficacy can be assessed by observing changes in the ultrasonic wavelength and waveform, which is a nondestructive method for mass cooling in the construction environment. Production and construction experience provided excellent reference for the sale of microbial concrete.

1. INTRODUCTION

Cracks are found to be one of the biggest problems in the history of concrete structures. The functions, performance and attractiveness are severely limited of the pulchritudinous concrete structures due to cracks which eventually makes the structure to face high maintenance service cost. Small Cracks were initially treated with injecting epoxy and large cracks which used to penetrate till full depth of concrete structures were difficult and crucial to fix. So now, the researchers around the globe have developed some self-healing technology for these different types of cracks, where the cracks are sealed or repaired without or with minimum human intervention.

Self-Healing technique seems to be the easiest way to heal the cracks. There have been numerous studies regarding self-healing techniques, but the best found is the Microbial method. Researchers claims it to be commercializing in many structures. The reason why this method is focused more for the upcoming development is because of its ecofriendly nature, as the crack's healing technology here is nothing but the metabolic activities of the bacteria. Detection cost for cracks is reduced along with the difficulty to repair it as it can heal cracks which difficult to access. The reduction in oxidation of steel is observed in many cases as the bacteria that are present has a good effect on density and compressive strength of concrete. This whole procedure reduces the cost of maintenance and also helps in keeping the environment safe by reducing the waste generated by manufacturing of concrete that would have been needed to repair the cracks.

There are some countries like China, Belgium, United Kingdom, Netherlands etc. who have successively made more than 10 demonstration projects between 2015-2020. These projects were mainly Tunnels, Basements Water channels etc. The main materials used were microbial self-healing concrete and microbial self-healing mortar.

2. MATERIALS

Different Common materials used in this type of concrete are supplementary cementing materials commonly known as SCM's. These types of materials contribute some properties of Hardened Concrete with the help of Pozzolanic or Hydraulic activity.

A common type of mixture contains OPC grade of concrete with P.O 42.5 with Fly ash class F (Low Calcium Ash) Grade-1 and GGBS Grade S95.

2.1. Mix proportion of concrete

According to different proportions of microbial self-healing bacteria are added, we obtain 3 different types of mix proportions.

- NC: Normal concrete
- PSC: Self-healing concrete with powder-based healing agent

Particle size = 65 – 120 μm cost increment = + 10.8$ or 783.51 ₹ (approx.)

- CSC: Self-healing concrete with capsule-based healing agent

Particle size = 3.2 – 4.0 mm cost increment = + 13.1$ or 950.38 ₹ (approx.)

These microbial healing agents replaced sand or mineral admixtures with their exact weight keeping the total weight per volume ratio as constant.

Types	Cement	Fly Ash	Slag Powder	Water	Water Reducer	Sand	Gravel	Microbial Healing Agent
NC	261	56	56	164	5.22	776	1072	0
PSC	261	56	43	164	5.22	776	1072	13
CSC	261	56	56	164	5.22	752.5	1072	23.5

Table 2.1.1: Mix Proportions of different types of concrete (Kg/m^3)

2.2. Detailed chemical composition.

CHEMICAL COMPOSITION	SiO_2	Al_2o_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI
Wt. (%)	22.27	6.86	3.12	62.11	1.53	0.62	0.19	2.01	1.29

Table 2.2.1: Detailed chemical composition P.O 42.5

CHEMICAL COMPOSITION	SiO_2	Al_2o_3	Fe_2O_3	CaO	MgO	F - Cao	SO_3	LOI
Wt. (%)	60.98	24.21	6.70	4.90	0.68	0.58	0.52	1.86

Table 2.2.2: Detailed chemical composition Grade – 1 Fly Ash

CHEMICAL COMPOSITION	SiO_2	Al_2o_3	Fe_2O_3	CaO	MgO	TiO_2	LOI
Wt. (%)	36.23	9.76	1.99	39.40	10.5	0.70	1.42

Table 2.2.3: Detailed chemical composition Grade S95 blast furnace slag

3. CREATION OF CRACKS IN LABORATORY

To test the effectiveness of the healing agents, concrete samples were cracked in 2 different methods. This provided us a wider range of effective results. First method emerged standard type of carks while the other method resulted in more logical and realistic cracks.

3.1. Standardized Cracks

A standard concrete sample of the dimension 160mm x 160mm x 70mm is set under use. The fresh concrete paste is cut to a depth of about 10 mm or 20 mm, with thin sheets of copper plate that is 0.3 mm thick. The visualization of copper plates in the concrete mold is shown in the Photograph 3.1.1.

After 24 hours, the plates were unfastened from the mold while demolding. Narrow groove of depth 10-20mm is observed with a width of 3mm.

Photograph 3.1.1- Mold for standardized cracks.

3.2. Realistic Cracks

There are different tests done to obtain realistic cracks, one of them is splitting test in which the concrete cylinders are wrapped into fiber reinforced polymer (FRP). We obtained 2 numbers of cylinders of 80mm diameter and 75mm in height from a concrete prism of dimensions 150mm x 150mm x 600mm. These concrete cylinders are covered or enveloped with tape and then the glass fiber reinforcement (Syncotype 625g/m^2) was enclosed all around, went out by the epoxy resin (2-component epoxy PC 5800). The tape will serve to prevent the contact between the resin and concrete specimens, so that when you remove the glass-fiber reinforcement, the test sample was obtained, the cylinder of the engine is ready for splitting test as shown in Photograph 3.1.2.

Photograph 3.1.2 - Splitting Test

An Amsler 100 D66/45 testing machine was put in action for the splitting test. The loading was continued till the crack was visible enough to be seen. Now once the cracks have appeared on the 75mm specimens, the specimens are cut into 3 pieces, each of 20mm height. Glass fiber reinforcement and tapes are then removed from the specimen and new tapes are again wrapped over upper, lower and the side surfaces of the crack's opening. Now the samples are fitted inside a PVC ring of outer diameter ± 109mm, inner diameter of ± 93mm and height 30mm. It's fitted with the help of epoxy resin (2-component epoxy PC 5800). The direct contact of epoxy is prevented with the upper and lower side of the specimen and the crack with the help of tape. Once the epoxy is hardened, the tape is removed.

After the bonding of PVC-ring with specimens, the crack width of each of the samples was measured by means of a computer program ImageJ. First, each sample was scanned with a piece of millimeter paper, with the help of a color photo scanner. The width of the crack can be determined by comparing the pixels that is occupied by the width of the crack on the millimeter paper. Now the crack length was divided into 15 equal lengths and width of each length was identified with this method. It was then easy to characterize the crack width of each specimen by the average width of the crack. All obtained crack in the test gave us a mean width ranging from 0.05mm to 0.87mm and the value of standard deviation was under 0.043mm.

4. SELF HEALING-EFFECT

4.1. Self-Healing Condition

Now, once the cracks are formed at an early age, the analysis of self-healing bacteria's accuracy is done by calculating the amount of regenerated concrete. Once the cracks are formed, Elastics are used to hold the specimen together while it is submerged into water at 25°C to promote healing. The difference between the distance of the top surface of concrete specimen and the surface of water is 10mm.

4.2. Characterization of the Healing Effect

The healing effect can be formulated straight from the area that is healed. While the concrete specimen is under the healing condition, images are clicked to make an account of the gradual healing percentage of crack. 0d, 3d, 7d, 14d, 28d and 50d are the time intervals for clicking the pictures. A digital camera is used to click the photos and then a software called ImageJ is used to process the pictures. Setting gray value in a section helps to differentiate between cracked and uncracked areas in the image. The cracked area was then obtained with the aid of the ultra-depth of-field microscope for the purpose of working out the number of pixels in the gap areas.

The percentage of self-healing was formulated by the following equation:

% Area of Self-Healing = $(A_0 - A_n) \times 100 / A_0$

Where, A_0 = Initial area of crack before healing

A_n = Area of crack healed in 'n' number of days

There is one easier way of determining average healing of crack on approximate basis which is commonly known as water permeability technique. We all know how voids play a vital role in determining the water permeability of a membrane or material. Here cracks play the role of voids in the concrete. Hence effect of healing directly shows the permeability percentage. Therefore, the impermeability ratio can be calculated by the self-healing effect after healing is observed in the material from 0-50 days. We can put it into the test by a self-made equipment (fig 4.2.1) where water is poured into the container and is checked for permeability under different conditions. Fig 4.2.1 shows a schematic diagram of the arrangement.

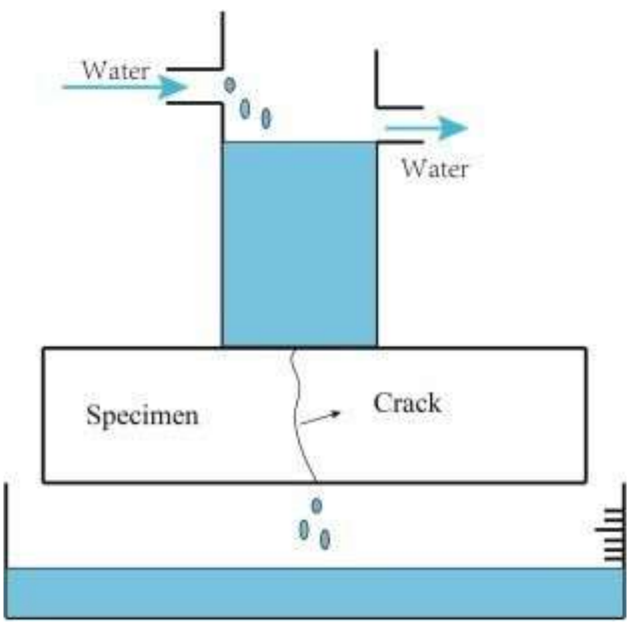

Figure 4.2.1 – Water Permeability Test

5. EXPERIMENTS DONE TO DETERMINE SELF HEALING

5.1 Macro Level Tests

Macro Level Tests are of great importance to achieve effectiveness of the self-healing concrete with specific treatment as it is used for its ability to restore its mechanical properties in a variety of conditions. Flexural, compressive, tensile, Splitting and non-destructive testing can be used to identify the mechanical properties.

Tests	**Efficient Healing Measurement**
Bending Test	Measure strength
Compression Test	Measure strength
Tensile Test	Measure strength
Splitting Test	Measure strength
Ultrasonic Pulse Velocity	Measure Tightness
Water Permeability	Damage, Healing Efficiency
Gas Permeability	Damage, Healing Efficiency
Corrosion Test	Corrosion Resistance

Table 5.1 - Macro Level Tests

5.2 Micro Level Tests

Micro Level Tests were performed to make sure the results are reliable. The purpose of these tests is to visualize the process of cracking treatment with mortar and morphology, to identify and interpret the accumulated matter after the healing process.

Tests	**Efficient Healing Measurement**
Optical microscopy	Visualization of healed crack
Scanning Electron microscopy	Visualization of crystal deposition
X-ray diffraction	Identification of crystal matter
Fourier transform infrared spectroscopy	Identification of crystal matter
Thermo-gravimetric analysis	identification of crystal matter
X-ray tomography	Visualization of healing
Neutron tomography	Visualization of healing

Table 5.2 - Micro Level Tests

5.3 Nano Level Tests

Nano Level Tests are conducted to make sure that the results are well grounded according to the theory. It is used to analyze and measure the mechanical properties at smaller volume for better efficiency.

Tests	**Efficient Healing Measurement**
Nano-indentation	Determination of Mechanical properties

Table 5.3 - Nano Level Test

6. FUTURE OBJECTIVES

Lab practices has shown that the microbial healing method can effectively repair concrete cracks in a particular environment. However, greater task remains to be done to bring the self-healing microbial concrete from laboratories to actual projects. For example, reducing the production cost of microbial healing agents, improve the self-healing effectiveness, reduce dependence on water-based healing, and establish technical specifications for microbial-healing of reinforced concrete. In addition, in the process of developing healing agents, powder and capsule-based healing systems are more suitable for current concrete production and sales and can reduce the modification of production equipment and production lines. Moreover, in construction, there is no additional load. It is noteworthy that the most important factor in pushing self-sustaining concrete into sales is still reducing the production costs of healing agents.

7. CONCLUSION

To promote the use of small-scale concrete technology in the concrete sector, a demonstration project was developed on the manufacturing technology of powder-based and capsule-based microbial healing agents and self-healing concrete construction technologies. A technical approach from the production of spore powder to improve the performance of the working field was initiated. In this review paper we get a clear idea about how self-healing properties not only involves physical, but also chemical process. Maximum amount of research has been carried out with the help of bacteria, as they have proven to be relatively effective in the treatment of cracks.

8. ACKNOWLEDGEMENT

I would like to express my special Thanks and gratitude to my faculty Mentor Prof. Avadhut Khirsagar who gave me the golden opportunity to work on this wonderful project on the topic of Self-Healing Concrete which helped me in knowing so many new concepts about the topic.

9. REFRENCES

1. ChunxiangQian, TianwenZheng, XuanZhang, YilinSu

   Application of microbial self-healing concrete: Case study

   Construction and Building Materials Volume 290 (2015)

2. S.-T. Yi, T.-Y. Hyun, J.-K. Kim

   The effects of hydraulic pressure and crack width on water permeability of penetration crack-induced concrete

   Constr. Build. Mater., 25 (5) (2011)

3. C.G. Berrocal, I. Lofgren, K. Lundgren, L.P. Tang

Corrosion initiation in cracked fibre reinforced concrete: influence of crack width, fibre type and loading conditions.

Corros. Sci., 98 (2015)

4. M.B. Otieno, M.G. Alexander, H.-D. Beushausen

in cracked and uncracked concrete – influence of crack width, concrete quality and crack reopening

Mag. Concr. Res., 62 (6) (2010)

5. K. Van Tittelboom, N. De Belie, W. De Muynck, W. Verstraete

Use of bacteria to repair cracks in concrete.

Cem. Concr. Res., 40 (1) (2010)

6. X. Zhang, C. Qian

Engineering application of microbial self-healing concrete in lock channel wall [J]

Mar. Georesour. Geotechnol. (2021),

7. X. Zhang, C. Qian

A new type capsule-based healing agent for concrete and its protective function of spores
Smart Mater. Struct., 29 (2020)

8. Mavjot Kaur, Krishna Murari, Inderpreet Kaur

Techniques and various efficiency evaluation tests for selfhealing cement-based matrix: State-ofthe-art

Materials Science and Engineering 814 (2020)

9. HuiRong, GuanqiWei, GuoweiMa, YingZhang, XinguoZheng, LeiZhang, RuiXu

Influence of bacterial concentration on crack self-healing of cement-based materials
Construction and Building Materials Volume 244, (2020)

10. Souradeep Gupta, Harn Wei Kua, Sze Dai Pang

Healing cement mortar by immobilization of bacteria in biochar: an integrated approach of selfhealing and carbon sequestration

Cem. Concr. Compos., 86 (2018)

11. K. van Breugel

IS THERE A MARKET FOR SELF-HEALING CEMENTBASED MATERIALS?

Proceedings of the First International Conference on Self-Healing Materials (2007)

12. Yunovich, M., Thompson, N.G.

Corrosion of highway bridges: Economic impact and control methodologies. Concrete Int., Vol. 25 (2003)